A METHOD FOR CONTROLLING PARACHUTE DEPLOYMENT CONDITIONS IN SIMULATED PLANETARY ENVIRONMENTS

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Presented at the Third National Conference on Aerospace Meteorology

New Orleans, Louisiana
May 6-9, 1968

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INTRODUCTION

The successful completion of many space missions requires that a high-velocity spacecraft be decelerated and soft-landed on a planet's surface. In those cases where the target planet has an atmosphere, the use of a parachute to provide at least a phase of deceleration once the incoming probe has entered the atmosphere is attractive since this is a system which is both rather simple and relatively lightweight. Until very recently, parachute performance data were limited to those environmental areas dictated by the requirement for successful operation below about 60,000 feet (about 20 km) altitude in the Earth's atmosphere. It is known that large differences may exist between the physical state of the Earth's atmosphere and that of other planets, so that if parachutes are to be considered for planetary applications their performance characteristics must be determined under conditions similar to those which most likely will be encountered on these other planets.

The NASA Planetary Entry Parachute Program (PEPP) was established in the latter part of 1965 at the Langley Research Center to provide performance data on several parachute configurations proposed for use under flight conditions which might be encountered by a spacecraft attempting to soft-land on the planet Mars (ref. 1). Specifically, the Mach number M and dynamic pressure q at parachute deployment influence parachute inflation and loadings and were the two parameters selected to be simulated. Based on available information, a combination of $M = 1.6$ and $q = 10$ psf (478 N/m^2) was considered typical for a Martian deployment at an altitude of approximately 15,000 feet (4.6 km) above the planet's surface. These conditions can be simulated in the Earth's atmosphere at altitudes above 100,000 feet (30 km). PEPP test objectives were to observe the deployment and inflation characteristics of each test parachute and to measure opening loads, all of which are greatly dependent on the initial Mach number and dynamic pressure deployment conditions. Additional objectives were to measure the drag and stability characteristics of the parachute during steady-state descent.

FLIGHT TEST METHOD

The two test techniques employed in the PEPP program are described in reference 1. One technique utilized a large high-altitude balloon to place a 15-foot (4.6-meter) diameter conical aeroshell at the proper altitude. The balloon was released and the system was accelerated by means of onboard rocket motors to the desired conditions where the parachute was deployed in the wake of the aeroshell. The second technique employed rocket-launched vehicles to drive a payload to the desired deployment conditions. Basic decelerator information was obtained without being concerned about the presence of the aeroshell wake. This paper concerns these latter tests.

For the rocket-launched tests, two-stage Honest John-Nike launch vehicles were employed. (At a later time in the series a third-stage Nike was added to increase the maximum attainable Mach number at a selected dynamic pressure.) The tests were performed at the White Sands Missile Range (WSMR), New Mexico, between November 1966 and October 1967. Eight successful deployments were accomplished. The flight sequence of events is presented in figure 1. The first-stage Honest John rocket motor provided the thrust for launch vehicle lift-off. The spent booster drag-separated at burnout. Second-stage (and third-stage when used) Nike ignition and separation from the payload (which contained the test parachute) were controlled by an onboard timer. A radio command system was used to start the onboard cameras and a second timer was programed to fire the mortar which ejected the test parachute 1 second after the radio signal was received. The 1-second delay was intended to give the cameras (located to view the deployment) time to attain a full running speed. In addition to the cameras, onboard instrumentation consisted of a tensiometer which measured the load in the parachute riser line, three orthogonally mounted accelerometers, and an attitude reference system (spin-stabilized gyro platform). These data were telemetered to ground receiving stations and recorded on magnetic tapes.

Radio Command Monitor Display System

Although the vehicle system was tailored such that the test payload would attain the desired combination of Mach number and dynamic pressure at a given time, a preflight trajectory dispersion analysis indicated a rather large variation could exist between the desired Mach number and dynamic pressure combination from that actually experienced if elapsed flight time were the only means available for initiating the parachute deployment sequence. In addition, it was known that significant variations in temperature and density from the 1962 U.S. Standard Atmosphere have been measured in the altitude region of interest (ref. 2). Since parachute inflation stability is influenced by Mach number and parachute

loadings are directly proportional to dynamic pressure and since the test parachutes were designed in some cases with small margins of safety, it was considered mandatory that some control be exercised over the test deployment conditions.

A radio command system was devised which when used with real-time flight trajectory data and the most recent meteorological data would greatly minimize the uncertainty which otherwise might be expected in the deployment conditions. Major elements of this technique are illustrated in figure 2. As illustrated, the payload was radar-tracked in flight. A transponder was included in the payload to insure a more accurate radar track. The slant range, azimuth, and elevation data were sent via microwave to the command control center. There the data were fed into a digital computer. The data first underwent a coordinate transformation to fix the origin at the launcher, and then altitude and total velocity (velocity relative to earth) were computed. To account for the known time delays in the system, the data were then projected to real time. Of course, this time-updating technique produced errors at those times in the flight when the acceleration changed suddenly (e.g., burnout); however, during the critical payload coast portion of the flight when changes in altitude and velocity with respect to time were small, this error was negligible. Altitude and velocity data, after being converted into an analog signal, were then fed to the arms of an X-Y plotter. The resulting real-time display of velocity variation with altitude allowed the command-control operator to determine the optimum time to send the radio signal to initiate deployment.

A meteorological sounding rocket was launched 1 day prior to the parachute test (t-1 day) to measure the atmospheric temperature profile in the region of interest above 100,000 feet (30 km). Atmospheric density was derived from the temperature data by the method described in reference 3. These temperature and density data formed the basis for determining the Mach number and dynamic pressure conditions at the time of deployment.

A sounding was also made as soon as possible after the parachute test and on the same day (approximately t+1 hour) for purposes of final reduction of the parachute flight data. This sounding also provided information concerning the validity of predicting temperature and density at test time from the previous day's sounding.

An altitude-velocity plot similar to that generated during a PEPP test is shown in figure 3. A typical flight history, showing the large increases in velocity resulting from the rocket motor thrustings and showing the payload coasting toward the test region, is also shown. To serve as a guide for determining when the radio command signal should be sent, grids of constant Mach number and dynamic pressure, such as are shown, for example, on the upper part of figure 3, were drawn on the plotting paper prior to launch time. These grids were derived by use of meteorological sounding rocket data from the previous day. That is, the speed of sound at any given altitude was calculated from the measured temperature data and used to obtain lines of constant Mach number. Density profiles were derived from the temperature profile with the aid of an atmospheric pressure "tie-on" point obtained from a rawinsonde measurement at about 80,000 feet (24 km) (ref. 3). An altitude overlap between rawinsonde-measured temperature data and the rocketsonde-measured temperature data provided a check on the validity of the atmospheric measurements. Dynamic pressure lines were then obtained with the aid of the derived density profile.

Through use of this technique, the Mach number and dynamic pressure values experienced by the payload were monitored at all times during flight. The radio command signal was sent when Mach number and dynamic pressure conditions were attained which were considered optimum for the desired test simulation. The altitude-velocity display was continually monitored subsequent to transmission of the command signal to determine whether parachute deployment and subsequent inflation had occurred. This would be evidenced on the plotting board as a sudden decrease in velocity with little gain in altitude, such as is shown by the example on the figure.

Sources of Error

The following list contains some of the factors mentioned previously which influence the Mach number and dynamic pressure combination attained:

- Rocket and vehicle system performance
- Radar, computer, plotboard
- Human response time
- Temperature measurement and density derivation
- Time variability

The performance of the launch vehicle system, which includes rocket motor performance, accuracy of timer functions, and the overall capacity of the vehicle to fly the planned trajectory, has a major effect on the Mach number and dynamic pressure combinations experienced. Through deviations in the rocket and vehicle system performance, the actual flight trajectory was always such that the desired set of test conditions were never attained simultaneously. It was therefore necessary to choose a set of acceptable deployment conditions which would cover a range great enough to include all possibilities which might be encountered. As an example, a desired combination of $M = 1.6$ and $q = 10$ psf (478 N/m^2) condition was enlarged to become $q = 12$ psf (574 N/m^2) for any $M < 1.6$ and $q = 10$ psf (478 N/m^2) for any $M > 1.6$. In this manner, dynamic pressure became the primary deployment criterion, principally because of the structural limitations of the test parachutes.

The overall effect of the radar tracking system and computer system operation on the accuracy of the analog display is influenced by many diverse sources. Errors in each system, however, can be minimized through proper care in calibrating the systems prior to use. Fortunately, radar tracking errors were small during the payload coast portion of the test since range, elevation, and azimuth were all slowly and smoothly varying. Computational losses are believed to be negligible and errors in time-updating the trajectory were minimized in the quasi-steady payload-coast part of the flight. With proper scaling of the X-Y plotter, it is believed that an overall accuracy of ±2 percent in both altitude and velocity can be realized. The response of the flight controller to events as they occurred in real-time on the altitude-velocity display was another source of error. (It is to be noted that he was required to anticipate the occurrence of the test point by 1 second, since, as discussed previously, his function was to start a timer.) Experience with preflight simulations has shown that a response time of ±0.25 second was normal, which for a typical flight would produce a ±0.3 psf (±14 N/m^2) uncertainty in dynamic pressure and a 0.02 uncertainty in Mach number.

Errors in calculating the M and q grids used on the visual display depended directly on the accuracy of the temperature measurement and the method of calculating density. Density was derived through the use of the hydrostatic equation and the equation of state (ref. 3). The "tie-on" rawinsonde pressure point was taken at an altitude where the measuring-system error is considered to be near a minimum. Errors in the temperature measurement due to conductive, radiative, aerodynamic, and electrical heating of the bead thermistor used as the sensing element in the rocket sounding were considered to be very small in the altitude region of interest. This sensing element then should be able to measure the atmospheric temperature within ±2° which for the altitude region of interest of the PEPP tests results in a Mach number uncertainty of ±0.5 percent. An overall uncertainty of ±3 percent in the derived density data appears to be an acceptable value. This, of course, would then produce a ±3-percent uncertainty in values of dynamic pressure. From a survey of the literature, the limited data available on short time period variations in the atmosphere above 100,000 feet (30 km) indicate variations in density from the mean of all measurements taken over a 24-hour period can be as large as ±5 percent. In reference 4, a diurnal temperature range of 15° to 20° near 55 kilometers decreasing to 5° C near 30 km was measured. Minimum temperatures were recorded near 0400 to 0600 MST with maximum values occurring near 1400 MST.

To summarize error sources then, it appears that by using meteorological data from a t-1 day sounding, in conjunction with good real-time velocity and altitude data, parachute deployment conditions can be controlled reasonably well. How well depends to a great extent on how close the parameters measured by the t-1 day sounding are to those at the time of the main test. As stated previously, in the PEPP series of tests, a sounding was made shortly after the primary parachute test to measure the atmospheric properties to be used in final data reduction. It was desired to have the t-1 day sounding occur 24 hours prior to the main test in order to minimize any diurnal effects in the physical state of the atmosphere. Any difference between the t+24 hour and t+1 hour soundings would be due to the change in local conditions from one day to the next.

METEOROLOGICAL DATA

Figure 4 was prepared to emphasize the need for meteorological soundings in direct support of the PEPP mission. This figure presents the variation of density profiles obtained from meteorological soundings made at WSMR in support of the PEPP mission from the 1962 U.S. Standard Atmosphere. The altitude interval within which PEPP deployments occurred is shown in the figure for reference. The trend from more dense to less dense atmosphere is in accordance with the change in seasonal means found to exist at White Sands (ref. 2). That is, during the winter months, the upper atmosphere on the average is less dense than the 1962 U.S. Standard, while during the summer a density higher than the 1962 U.S. Standard is typical. The spring and fall serve as transition periods and more closely represent the yearly or "standard atmosphere." The variation from the Standard Atmosphere did become as high as 20 percent for these PEPP support soundings; variations as high as 30 percent have been reported in the 100K to 180K (30 km to 55 km) altitude for WSMR (ref. 2).

It is obvious that if the 1962 U.S. Standard Atmosphere was used to construct the M and q grids on the monitor display, the uncertainty in the q lines would directly reflect the uncertainty due to the density variability from the Standard.* However, to be of any real benefit, the sounding used to construct the M and q grids must be representative of the physical state of the atmosphere at test time. The variation between the t-1 day and t-day density data is shown in figure 5 for the three PEPP tests where good soundings on 2 successive days were obtained. The data, although limited, indicate less than 4-percent variability below 150,000 feet (46 km). For those cases where a morning sounding was made on one day and an afternoon sounding on another, a difference greater than 4 percent was measured above 150,000 feet (46 km). This larger difference might result from the combination of a diurnal factor added to the normal day-to-day change. Fortunately, all but one of the PEPP tests were below 150,000 feet (46 km).

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*Subsequent to the completion of the PEPP test series, U.S. Standard Atmosphere Supplements, 1966, which contains some information on seasonal mean values of density, has been published.

CONCLUDING REMARKS

The Mach number and dynamic pressure combinations obtained during the PEPP series are shown in figure 6. The deployment dynamic pressure criteria, which were $q = 10$ psf (478 N/m^2) for $M > 1.6$ and $q = 12$ psf (574 N/m^2) for $M < 1.6$, are also shown for reference. Based on the uncertainties in radar-derived velocity, temperature measurement, and calculated density, the uncertainties in M and q are approximately ± 0.02 and ± 0.4 psf (± 19 N/m^2), respectively (indicated by the diameter of the circle about each data point). Values of temperature and density used to calculate M and q were taken from the t-1 day sounding in those cases where no t-day meteorological data were available. Thus, no attempt was made to include the effects of time variability of the meteorological data in the uncertainties in these deployment conditions.

PEPP experience has shown that parachute deployment conditions (Mach number and dynamic pressure) can be controlled effectively by the utilization of a radio command system when the test payload velocity and altitude are known on a real-time basis and recent meteorological data are available. For this program recent meteorological data aided in determining the approximate temperature and density profiles which existed during that time of the year just prior to a PEPP test. Using a sounding as close as possible to a time 24 hours prior to the parachute test most likely further reduced the uncertainty in predicting the physical state of the atmosphere by minimizing diurnal effects. For applications such as this, additional data are highly desirable concerning diurnal and day-to-day variations in order to minimize uncertainties and to increase confidence in this technique.

Results from the PEPP test series are limited. In only three out of nine of the launches which comprised the series were meteorological data available one day before as well as on the test day. Although the reason for such a limited number was in some cases due to scheduling limitations, more often the primary reason was failure of a sounding to produce usable data because of some failure within the meteorological sounding system. A more reliable system for gathering meteorological data above 100,000 feet (30 km) on an operational basis would contribute significantly in future tests of a similar nature.

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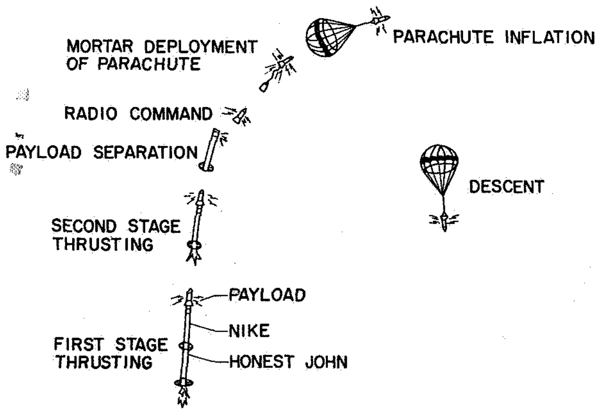

Figure 1.- Flight sequence of events.

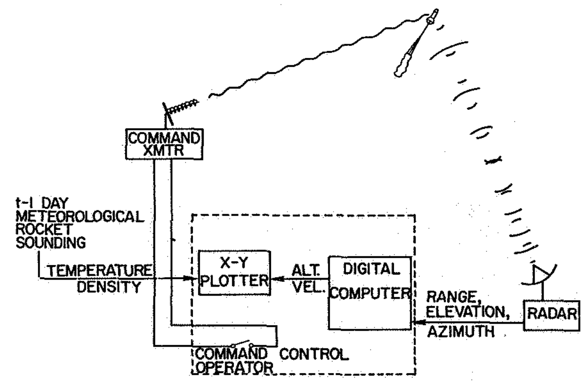

Figure 2.- Radio command deployment technique.

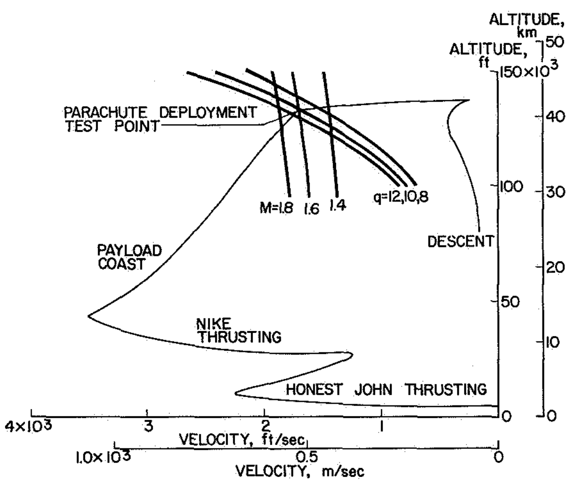

Figure 3.- Visual display for command deployment.

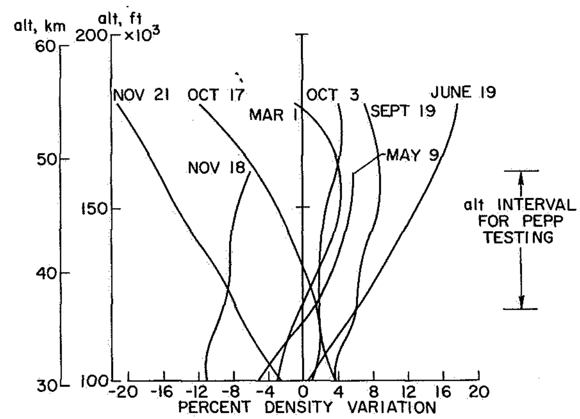

Figure 4.- Variation of measured atmospheric density profile from 1962 U.S. Standard Atmosphere for specific PEPP tests.

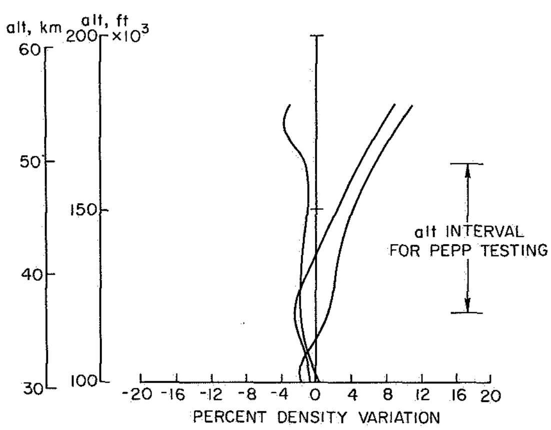

Figure 5.- Variation between t and t - 1 day atmospheric density profile.

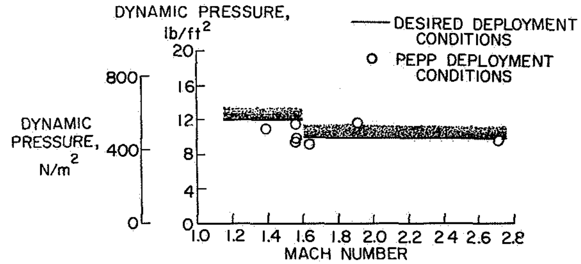

Figure 6.- Mach number and dynamic pressure deployment conditions for PEPP tests.

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